MECHANICAL CONTROL OF SHIP-BOTTOM FOULING BY MEANS OF AIR BUBBLES[1]

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During the year 1943 investigations were carried out for the purpose of determining the effect of water currents upon the attachment of fouling organisms to submerged surfaces. As a result of these experiments it was demonstrated that a comparatively low water velocity applied continuously would prevent fouling (Smith, 1946). In the case of the species of barnacles most prevalent at Miami, a velocity of slightly more than one knot was sufficient to prevent attachment. It was also shown that barnacles which have been allowed to attach and remain undisturbed for a period of six hours are washed from their hold by currents in the order of 2½ to 3 knots.

Following these experiments attention was given to the manner in which water currents might be directed over a ship's hull, propellers or external portions of the sound apparatus for the purpose of preventing fouling. Dr. I. G. Slater of the British Admiralty Delegation advanced the suggestion that the necessary current might be produced by air bubbles. Experiments were initiated to determine whether it was in fact possible to inhibit fouling in this manner and subsequently to determine its economic practicability.

Since the completion of these experiments attention has been drawn to U. S. Patent No. 2138831, December 6, 1938, granted to F. G. Branner, relating to the use of gas bubbles released below ship's hulls for the purpose of preventing attachment of fouling organisms (Branner, 1937). Nothing in the specifications, however, suggests that the device has been subjected to biological investigation.

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Panel Tests

Glass panels 8″x12″ in size were submerged at an angle of 45 degrees, with the upper edge a few inches below and parallel to the surface of the water. In order to insure the known optimum conditions for the attachment of fouling organisms, black Cararras glass was used. Included in the floating frame containing the experimental panels were untreated control panels. The experimental surfaces were subjected to air bubbles by means of perforated plastic tubes situated close to the lower edges and connected to an air compressor (Figure 1). Results are shown in the photographs and are summarized in Table I.

The first test consisted of an untreated control panel, and two panels each subjected to air bubbles along a 3½ inch length of the base. At the base of one of the latter the bubbles were liberated from comparatively large holes about 1/16 of an inch in diameter and 1 4 inch apart. In the case of the other the holes were smaller, approximately 1/32 of an inch in diameter and 1/8 of an inch apart. Air released from the holes was measured by means of an inverted graduate and funnel. From the time required to fill the graduate the rate of air flow from the perforated 3½ inch lengths of tubing was calculated as approximately 0.4 and 0.2 cubic feet per minute for large and small bubbles respectively. Converted to units of cubic feet per minute per foot of perforated tubing these rates of flow are 1.3 and 0.6. Following a 48 hour period of exposure, beginning on May 18, the panels were examined for cyprids and metamorphosed barnacles. The number of these observed upon the control was 239. Upon the panel subjected to the smaller bubbles 85 barnacles had attached, but were confined to that half of the panel not subjected to bubbles. The remaining panel, subjected to the larger bubbles, had acquired 74 barnacles on the untreated half and the clear area extended well to one side of the bubble treated half.

The experiment was allowed to continue for a further 7 days before the panels were removed and photographed. It was observed that whereas heavy fouling had occurred upon the control (Fig. 1c), the treated surfaces were free of barnacles, and that in the case of the large bubbles the protected area was somewhat wider than the 3½ inch perforated length of tube at the base of the panel (Fig. 1a).

Since the results of the first test indicated beyond doubt that the attachment of fouling organisms might be prevented by air bubbles, a second test was designed to determine the minimum rate of airflow required to produce the anti-fouling effect. Three panels were used in this test, with airflows of approximately 1.3, 0.6 and 0.2 cubic

TABLE I

Effect of Air Bubbles upon Fouling of Glass Panels

Series and Experiment	Date Started	Air Flow in Cu. Ft. per min. per foot	Diameter of Perforations	Distance between Perforations	Exposure Period	Observations
I (a)	5–18–44	1.3	1/16″	1/4″	2 days	No cyprids
(b)		0.6	1/32″	1/8″	2 days	No cyprids
(c)		Control	....	....	2 days	Many cyprids
(a)		1.3	1/16″	1/4″	9 days	No fouling. Clear area extends beyond length of perforated tube.
(b)		0.6	1/32″	1/8″	9 days	No fouling
(c)		Control	....	....	9 days	Fouling
II (a)	7–10–44	1.3	1/32″	1/4″	14 days	No fouling
(b)		0.6	1/32″	1/4″	14 days	No barnacles. Bryozoa grow in from side.
(c)		0.2	1/32″	1/4″	14 days	Completely fouled
III (a)	7–24–44	0.6	1/32″	1/2″	25 days	No barnacles. Bryozoa grow in from side.
(b)		0.6	1/32″	1″	25 days	Same
(c)		Control	....	....	25 days	Completely fouled
IV (a)	9– 8–44	0.6 (Stopped daily for 4 hours)	1/32″	1″	18 days	Scattered barnacles
(b)		Control	....	....	18 days	Heavy fouling.

feet per minute per foot, respectively, liberated as bubbles through 1/32 of an inch diameter holes spaced at 1/4 of an inch intervals over a length of 3 inches. At the end of 14 days exposure the set of bubbles released most slowly was found to have permitted attachment of barnacles. Nevertheless, barnacles were less numerous over the bubble treated area than over the untreated edges of the panel. The two remaining panels were free of barnacles over the area covered by the bubbles. In the case of the most rapidly released bubbles the unfouled area extended beyond the 3 inch length of perforated tubing. The panel with the intermediate rate of bubbling showed growth of bryozoa inwards from the fouled area into the unfouled area. In all three panels a thin slime film formed towards the edge of the clear area but was less marked in the middle of the area or nearer to the source of the bubbles. The results of this series indicate that the minimum rate airflow required for anti-fouling lies between 0.2 and 0.6 cubic feet per minute per linear foot.

A third experiment was carried out to test the possibility of using bubbles spaced at wider intervals. Perforations of the copper tubing beneath one panel were 1/2 inch apart, and beneath a second, 1 inch apart. The holes were 1/32 of an inch in diameter and covered a length of six inches. Rate of airflow was 0.6 cubic feet per minute per foot in both cases. A third panel remained untreated as a control. At the end of 25 days exposure the control was heavily covered with barnacles, tunicates and bryozoa. The other panels were free of barnacles and tunicates, but some filamentous bryozoa had begun to grow in from the sides. It appeared that bubbles spaced at 1 inch intervals were as effective as when spaced at 1/2 inch intervals.

The effect of intermittent bubbling was investigated by means of panels similar to those used in previous experiments. The perforations were 1/32 of an inch, spaced 1/2 inch apart, and extended the width of the panel. The rate of airflow was about 0.6 cubic feet per minute per foot. On each day during the test the air was turned off for a period of four hours. The experiment was continued for a period of 18 days before removal from the water for examination. Whereas the untreated control panel had accumulated heavy fouling, the panel subjected to the intermittent flow of bubbles had only a few scattered barnacles upon its surface. These were of various sizes and had apparently attached during the entire period of the experiment. These results indicate that some of the barnacles which had attached during a four

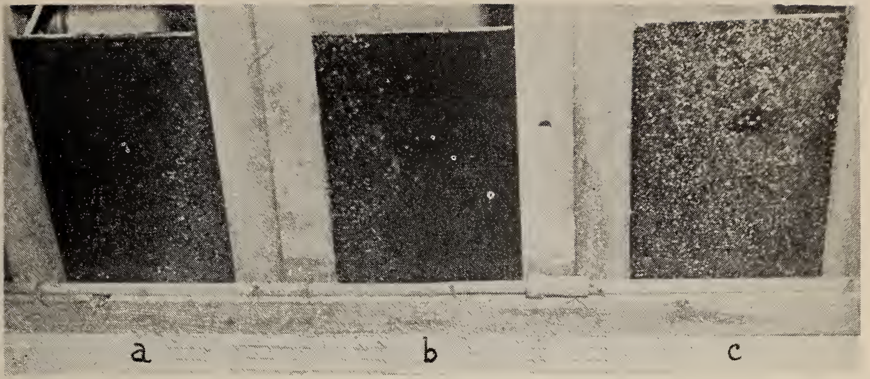

Figure 1.

(*a*) Panel subjected to 1.3 cubic feet of air per minute per foot, liberated from perforations 1/16 of an inch in diameter, 1/4 of an inch apart in 3 1/2 inches of panel width. Exposed 9 days.

(*b*) Similar, but with air flow 0.6 cubic feet per minute per foot.

(*c*) Control panel with no air bubbles.

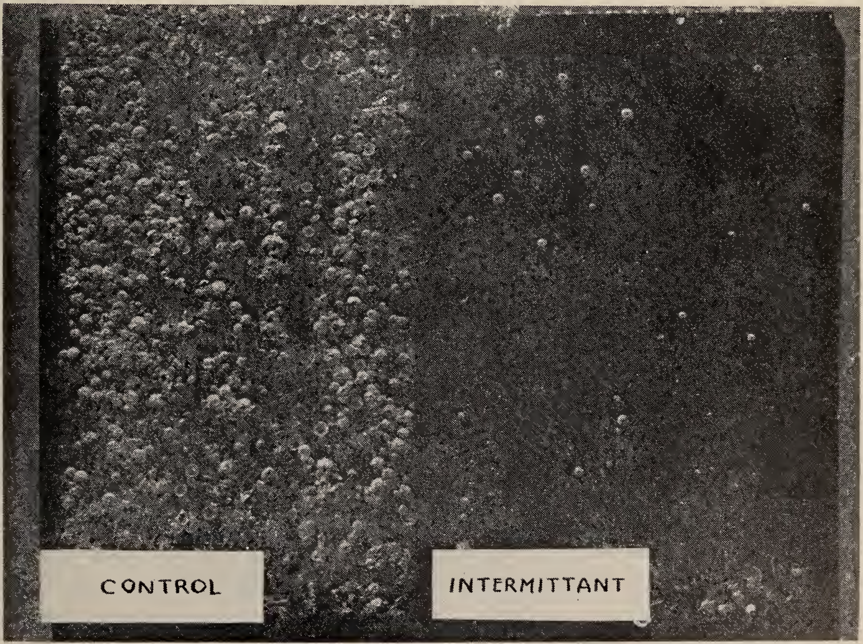

Figure 2.

(*Right*) Panel subjected to bubbles for 20 hour periods alternating with 4 hour periods of rest. Airflow 0.6 cubic feet per minute per foot liberated from 1/32 of an inch diameter perforations, 1 inch apart. Exposed 18 days.

(*Left*) Control.

Figure 3.

Stern of M.V. *Nauplius* showing air tubes. Bubbles released on port (left) side of keel only. Three weeks' test using 3 h.p. compressor.

Figure 4.

Portion of bottom amidships from starboard showing untreated area at left (sternwards) and area subjected to bubbles at right (forwards). Same conditions as Figure 3.

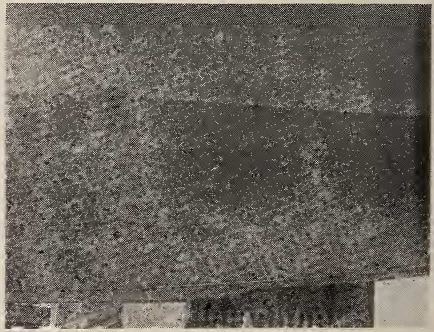

Figure 5.

More general view amidships, similar to Figure 4, but showing fouling due to lack of bubbles toward the bow.

hour period not subjected to air bubbles were still able to develop when the air bubbles were resumed (Fig. 2).

The small number of these may indicate that only the more hardy are able to survive under these conditions. Although cyprid attachments were low on other test panels during the period of this experiment, a comparison of the experimental and control panels shows that had the intermittent bubbling not been effective a far greater number of barnacles would have attached during the daily four hour period and have developed than actually occurred.

Service Tests

In order to demonstrate the bubble method and in order to investigate the practical difficulties which might be encountered in applying it to the actual protection of ships' bottoms, service tests were carried out upon the University of Miami Marine Laboratory motor vessel, the *Nauplius*. The vessel is a 29 foot fast cabin cruiser, fitted with twin engines and capable of speeds in the order of 20 knots. Immediately behind the bow the sides of the hull arise at an angle close to the vertical. At the stern the hull is almost horizontal with a slope of approximately one in eighteen. It was thus possible in using this vessel to test the effect of bubbles on hull surfaces at widely varying angles to the vertical. A false keel 2″x 2″ in cross section was fitted to the vessel and to each side of this were fastened 1/2″ copper tubes, running the length of the vessel and passing vertically upwards at the stern to the deck where regulating valves and air hose attachments were arranged (Fig. 3). The copper tubes were perforated over a length of 12 feet at the after end of the portside and for a distance of 12 feet at the forward end of the starboard side. The holes were spaced at 1/2″ intervals and were 1/32 of an inch in diameter. Air was supplied from a one-half horsepower compressor, delivering 2 to 3 cubic feet per minute. Old paint on the bottom was burned off and a light green topside paint applied. Immediately after launching the compressor hose was attached to the vessel and air bubbles were applied to the hull. The compressor was inadequate for the purpose and difficulties arose, owing to the variation in depth of the keel below the water line. As a result of this, air was liberated more readily from the higher parts of each of the two tubes. Bubbles were therefore confined to areas of the hull extending over the after 3 or 4 feet on the portside and over a similar distance on the starboard side immediately forward of amidships. Air was applied continuously whenever the *Nauplius* was moored in dock.

The experiment continued for a period of five weeks, during which the vessel was used for various purposes at sea. When not lying at her dock the air hose attachment was removed immediately before getting under way. The speed of operation varied between 10 and 20 knots, except when plankton nets or other trolling equipment was being used. When away from her dock the vessel was not allowed to remain stationary for periods of more than a few minutes. At the end of the exposure period the *Nauplius* was hauled and the bottom examined. Although fouling was substantially reduced on the portions of the hull subjected to air bubbles, nevertheless barnacles were scattered over these surfaces. It was particularly noted that even over the almost horizontal portion at the stern, air bubbles had afforded as much protection as over the more steeply inclined portion amidships. Propeller struts obstructed bubbles and caused fouling beyond.

A second test was carried out upon the same vessel, using a more powerful compressor. This was operated by a 3 horsepower motor and delivered 15 cubic feet per minute. The same arrangement of copper tubes and perforations was used. Other conditions were essentially the same as in the previous experiment.

At the end of three weeks the vessel was again hauled (Figs. 3, 4 and 5). The contrast between protected and unprotected areas was greater than in the previous experiment, and the bubbles had covered a greater area of the hull. Nevertheless, at the deepest part of the hull, lying between the bow and midship section, bubbles had not been released, and fouling had occurred. A length of 2 feet immediately behind the bow had also become fouled due to failure of the bubbles to be released from the forward end of the copper tube (Fig. 5). .

It was demonstrated by the foregoing results that air bubbles, when released at the keel at a sufficient rate, provided anti-fouling protection. At the same time it was demonstrated that the varying depth of the keel caused an unequal distribution of bubbles, resulting in a lack of protection above the lowest points of the keel.

Discussion

The results of the panel tests indicate quite clearly that submerged surfaces may be protected by means of air bubbles. Service tests on the M.V. *Nauplius* also demonstrate that the protection applies equally well to flat bottom hulls as well as to bottoms arising more sharply.

The panel experiments have also shown that holes as small as 1/32 of an inch in diameter and as far apart as 1 inch will provide a sufficient flow of air bubbles.

Of more importance from a practical point of view is the actual volume of air required to protect a vessel, and the power needed to provide this. From the second and third panel tests results were obtained which showed a flow of 0.6 cubic feet per minute to be ample protection for each horizontal foot of the ship's bottom. It is possible that as little as half of this would be sufficient since the next lowest rate of flow which was found to be unsatisfactory was 0.2 cubic feet per minute per foot. Nevertheless, even were a rate of 0.3 cubic feet per minute per foot satisfactory it would necessitate a total of 18 cubic feet per minute in order to cover both sides of the bottom of a 30 foot vessel. For this purpose a four horsepower compressor would be required. With larger vessels the power necessary to provide air bubble protection would increase not only with the length of the vessel but also with the depth of the keel, though to a lesser extent.

The problem of discontinuity of air bubble release with varying keel depth remains to be solved. The solution may lie in separate treatment of sections of the bottom according to the depth of the keel. Bilge keels and similar projections would necessitate auxiliary tubing.

The possibility of using intermittent bubbling has not been clearly proved by the panel test. Were this possible the power needed for protection of the hull might be cut down by a system of treating several sections of the hull alternately.

A suggestion by Dr. Slater that the anti-fouling effect of the air bubbles might be due to action upon the attached young of fouling organisms rather than through production of water currents raises theoretical questions. Nothing observed in the foregoing experiments offers evidence on this point. Although it might be argued that the protection of a flat bottom must be due to some direct mechanical action upon the attached young of fouling organisms rather than through production of water currents raised theoretical questions. Nothing observed in the foregoing experiments offers evidence on this point. Although it might be argued that the protection of a flat bottom must be due to some direct mechanical action of the air bubbles, yet it was observed that the bubbles rose from the edges of the flat bottom as quickly as from other portions of the hull and could quite possibly have created as strong a water current along the bottom.

The service tests show that it might be possible to prevent fouling of